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ORIGIN OF THE OLIGOCENE AND MIOCENE DEPOSITS OF THE GREAT PLAINS.

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Skirting the base of the Rocky Mountains and covering the surface of the plains for some two or three hundred miles to the eastward is a series of Tertiary clays and sandstones with a combined maximum thickness of over 1700 feet. This extends from the Rio Grande in southern Texas to and beyond the northern limits of the Black Hills in South Dakota, and covers the greater portion of the plains of eastern New Mexico and Colorado, southeastern Wyoming and western Texas, Oklahoma, Kansas, Nebraska and South Dakota. Within this 1700 feet of Tertiary deposits there are a number of different horizons, which are usually quite distinct both faunally and lithologically. The more important of these were long ago differentiated and given appropriate names by Hayden, Leidy, Cope, and others. If we exclude the Equus beds and certain other deposits at the top, of Pliocene and Pleistocene age, and which do not fall within the limits of this paper, this entire series of rocks has been considered to belong to two formations, the White River, or Oligocene, and the Loup Fork, or Miocene. The White River, so named from a stream in northwestern Nebraska and southwestern South Dakota, where it is particularly well represented, is the lowermost, and therefore the older of these two formations. It has a maximum thickness of about 700 feet and consists for the most part of very fine and usually unlaminated clays, with frequent lenses of sandstones which in places become so coarse

as to appear as conglomerates. Less frequently there are strata of limestone. These are usually only an inch or two in thickness, though occasionally attaining to as much as a foot. They are always of quite limited extent laterally.

The White River formation has been subdivided into the Titanotherium and Oreodon beds, the former at the base, the latter at the top of the series. The Titanotherium beds have a maximum thickness of about two hundred feet, and are composed of very fine, white, reddish- or greenish-colored clays with numerous lenses of sandstones and conglomerates, not faunally distinguishable, however, from the clays. The Oreodon beds, with apparently slight local unconformities, immediately overlie the Titanotherium beds. They have a maximum thickness of five hundred feet and consist of brown or pinkish-colored clays, banded but usually not laminated except at one or two horizons where distinct lamination is plainly visible. The clays of the Oreodon beds are interrupted by sandstone lenses, though less frequently than are those of the Titanotherium beds, and the sandstones of the upper series are usually of a much finer grain than are those of the lower. Toward the bottom of the Oreodon beds in the Bad Lands of South Dakota, there is a series of sandstone lenses known as the Metamynodon sandstones. These sandstones are faunally distinct from the surrounding clays. At the top of the Oreodon beds in the same region, these sandstone lenses are replaced by a second series very similar lithologically to the first, but quite distinct faunally. These upper sandstone lenses have been called the Protoceras sandstones. Their fauna differs not only from that of the lower Metamynodon sandstones, but from that of the adjoining clays as well. While the Metamynodon and Protoceras sandstones are faunally quite distinct, both from one another and from the adjoining and underlying clays, sandstones and conglomerates of the Oreodon and Titanotherium beds, they are, in so far as is at present known, of extremely local distribution. At present neither of these two series of sandstones has been recognized outside of a very limited area in the South Dakota Bad Lands. Here they appear as lenses marking the course of an ancient river channel, that in Oligocene times crossed these plains in a direction almost at right angles to the present courses of the Cheyenne and White Rivers, now the two principal streams of this immediate region. On the same horizon with the Protoceras sandstones and contemporaneous with them in

origin, there is in the South Dakota Bad Lands a series of pinkish-colored nodular clays. These clays are faunally quite distinct, both from the adjoining sandstones and the underlying clays of the lower Oreodon beds. Unlike the Matamynodon and Protoceras sandstones, this upper series of clays is of wide distribution and has been recognized in South Dakota, Nebraska, Wyoming and Colorado. Dr. W. D. Matthew, in his most excellent memoir on the *Fossil Mammals of the Tertiary of Northeastern Colorado*, has very appropriately named these clays the *Leptauchenia Beds*, from a genus of fossil mammals occurring abundantly in them.

From the above remarks it will readily appear that the White River formation may be separated faunally into three sub-equal primary divisions. These are, commencing with the lowermost, as follows:

1. *The Titanotherium Beds*, consisting of 200 feet of fine, white or greenish-colored clays with numerous intercalated lenses of sandstones and conglomerates, the latter not faunally distinguishable from the clays.

2. *The Oreodon Beds*, consisting of 300 feet of pinkish-colored, banded and frequently nodular but usually unlaminated clays, with less frequent lenses of finer sandstones, faunally distinct and known as the *Metamynodon sandstones*.

3. *The Leptauchenia Beds*, consisting of 200 feet of pinkish-colored, often nodular and banded, but unlaminated clays, including the *Proteceras sandstones* above referred to.

The *Loup Fork* was the name given by Cope to a series of sandstones and clays well represented in western Nebraska and Kansas. This formation has since been found to have a very wide distribution, and to extend almost uninterruptedly all along the eastern base of the Rockies from Mexico to the Missouri River. It attains its greatest development in southeastern Wyoming and northwestern Nebraska, where it has a thickness of more than 1500 feet.

The sediments of the Loup Fork formation have not been so thoroughly studied as those of the White River, and their faunal and lithological characters are consequently less perfectly known. The latest attempt at a differentiation of the various horizons within the Loup Fork is that of Darton. Chiefly by lithological characters he has divided the Loup Fork of northwestern Nebraska into three divisions. Commencing below these are:

1. *The Gering Sandstones.*—These consist of some 200 feet of laminated, massive and cross-bedded sandstones, found either conformably or unconformably overlying the White River formation at various localities in western and northwestern Nebraska. They are well shown at the mouth of Monroe Creek cañon, some five miles north of Harrison, Sioux County, Nebraska. Few fossils have been found in these sandstones.
2. *The Arikaree Sandstones.*—These consist of some 500 feet or more of light-gray, soft, massive sandstones, everywhere characterized by numerous, flattened, horizontally columnar, hard, dark-gray concretions. These concretions have an average vertical thickness of about one foot; they are frequently several yards in width and often several hundred feet in length. They have a general northwesterly and southeasterly trend. The Arikaree sandstones are especially well developed in the northern face of Pine Ridge, in Sioux County, Nebraska, and Converse County, Wyoming. In this region these sandstones may be conveniently subdivided into an upper and lower series, easily distinguishable both by faunal and lithological characters. These subdivisions in the Arikaree will be referred to and fully described later.
3. *The Ogalalla Formation.*—This consists of a series of calcareous grits, loose brown sands and clays with occasional coarse conglomerates, the whole attaining to an aggregate maximum thickness of 300 feet. It is the equivalent of the *Goodnight* (Palo Duro) beds of Texas and Kansas, and is especially well developed in western Nebraska and Kansas, between the Platte and Arkansas Rivers. It is usually referred to the Pliocene, but a portion, or all of it, may yet prove to belong to the Miocene.

Returning to the Arikaree formation, I have already remarked that in Sioux County, Nebraska, and Converse County, Wyoming, it is lithologically and faunally divisible into two easily distinguishable horizons. Commencing below, these may be named and characterized as follows:

1. *The Monroe Creek Beds.*—These are well shown in the northern face of Pine Ridge, at the mouth of the Monroe Creek cañon, five miles north of Harrison, Nebraska, where they overlie the Gering sandstones, and are composed of some

300 feet of very light-colored, fine-grained, not very hard, but firm and massive sandstones. On account of their usually barren nature they have been neglected by collectors, and very little is known concerning their fauna beyond the fact that toward the top they contain Promerycochœrus. They decrease in thickness very rapidly to the eastward and increase to the westward.

2. *The Harrison Beds.*—These are well shown in the bluffs of all the small streams that head near the summit of Pine Ridge, in the vicinity of Harrison, Nebraska. They are also known to cover a considerable area to the east, west and south of that village, extending well into the State of Wyoming. They are composed of about 200 feet of fine-grained, rather incoherent sandstones, permeated by great numbers of siliceous tubes arranged vertically rather than horizontally. They are further characterized by the presence, often in the greatest abundance, of those peculiar and interesting, but as yet not well understood, fossils known as Dæmonelix, and by a considerable variety of fossil mammals belonging to characteristic Miocene genera. They immediately and conformably overlie the Monroe Creek beds and pass insensibly into them. Above these come:

The Nebraska Beds, of Scott.—These consist of a series of buff-colored sandstones of varying degrees of hardness and unknown thickness, with occasional layers of siliceous (not calcareous) grits, which protrude as hard, indurated or shelving masses from the underlying and overlying softer materials. These beds are rich in vertebrate fossils, such genera as Cosoryx, Protolabis, Cyclopidius and Merycochœrus predominating. They are represented at various localities along the Niobrara River, south of Harrison, Nebraska, where they are of unknown thickness and immediately overlie the Harrison beds. Toward the south they pass beneath the Ogalalla formation.

According to the above classification all the Miocene deposits of this region are referred to the Loup Fork, notwithstanding their great thickness and, in certain localities at least, their apparent conformity with the underlying Oligocene deposits, and without regard for the fact that throughout the lowermost 500 to 1500 feet of these sediments there is as yet practically no paleontological evidence as

to their exact age and correlation. Considering the absence of such direct paleontological evidence, it may be just as well to continue to refer this entire series to the Loup Fork; but I believe it more probable that the Gering sandstones, and perhaps a portion at least of the overlying Monroe Creek beds, will prove eventually to belong to the John Day rather than the Loup Fork. The maximum thickness of these two formations in Converse County, Wyoming, can hardly be less than 1500 feet, and almost nothing is known of the fauna of this entire series. Although for the most part quite barren of fossils, it would seem that somewhere throughout its great vertical and lateral extent there must be fossiliferous horizons, and that within these representatives of the John Day fauna will yet be found. The paucity of these beds as compared with the great wealth of fossils in the underlying and overlying deposits, have heretofore caused them to be almost totally neglected by collectors. I believe a better classification of these beds would be obtained by making Darton's Arikaree coördinate with the Loup Fork, including within it the Gering sandstones and Monroe Creek beds, correlating it provisionally with the John Day.

The following table is submitted as expressing the present author's views as to the proper classification of the Oligocene and Miocene deposits of this region. It is based on our present knowledge of the faunal and lithological characters of the various horizons as they have been determined, chiefly in northwestern Nebraska and southwestern South Dakota, where these deposits are best represented and have been most thoroughly studied.

TABLE OF OLIGOCENE AND MIOCENE FORMATIONS OF WESTERN PLAINS.

Miocene.	Loup Fork.	Goodnight = Palo Duro = Ogalalla.
		Nebraska = Upper Deep River.
		Harrison = Hiatus between Lower and Upper Deep River.
	Arikaree.	Monroe Creek = Upper John Day and Lower Deep River.
		Gering Sandstones = Lower John Day.
Oligocene = White River.		Leptauchenia Clays, including Protoceras Sandstones.
		Oreodon Clays, including Metamynodon Sandstones.
		Titanotherium Sandstones and Clays.

The writer is well aware that the above correlation of the Gering and Monroe Creek sandstones is open to criticism, as being at present inadequately substantiated by direct paleontological evidence. However, it should be remembered that on the other hand there are no direct paleontological evidences against such correlation, and that since sedimentation seems to have been continuous at certain localities in this region, from the base of the White River to the top of the Loup Fork, the John Day should be represented somewhere in the series, and that the lithological sequence, as well as the faunas of the overlying and underlying rocks, point to the Gering and Monroe Creek sandstones as the logical representatives of the John Day formation in this region.

Origin of the Deposits.

Until very recently the sediments of this entire series of deposits have been very generally considered as of lacustrine origin, and the boundaries of these supposed great Oligocene and Miocene lakes have been set forth in text-books and scattered papers, and especially in the classroom lectures on the subject at our various universities, with a preciseness only surpassed by that of the modern geographer when dealing with existing lakes.

The earlier writers, including David Dale Owen, King, Hayden, Leidy, Cope, Marsh and others, were always accustomed to speak of these deposits as lacustrine, and they are at present so considered by many authorities. Recently, however, their lacustrine origin has been rejected, at least partially, by a considerable number of competent observers, several of whom have had most excellent opportunities for studying them. This is especially true of the upper or Loup Fork series of deposits, which has now come very generally to be considered as of combined lacustrine, fluviatile, flood-plain and æolian origin, instead of as having been laid down over the bottom of a great and continuous body of water, as was formerly supposed.

With regard to the origin of the underlying White River series, however, it has been different; and with a few exceptions these deposits are still regarded as of lacustrine origin. Dr. W. D. Matthew, in an article entitled "Is the White River Tertiary an Æolian Formation?" published in the *American Naturalist*, for May, 1899, was the first to seriously question the lacustrine origin of these deposits. In his "Fossil Mammals of the Tertiary of

Northeastern Colorado," published as Part VII of Vol. I of the *Memoirs of the American Museum of Natural History*, Dr. Matthew has set forth additional facts in favor of his æolian theory as to the origin of the deposits, which, if not furnishing conclusive evidence as to the correctness of his theory, at least make it very clear that the lacustrine theory is alone unable to explain many well-known facts relating to the nature of these deposits and the distribution, condition and nature of the animal remains found in them. W. D. Johnson, in his paper on "The High Plains and their Utilization," published in the Twenty-first Annual Report of the United States Geological Survey, has entirely ignored the lacustrine theory of the origin of any of the Tertiary deposits of the plains, holding that they are of fluviatile and flood-plain origin, while Dr. J. C. Merriam, in a recent paper on "The Geology of the John Day Basin," rejects the lacustrine theory of the origin of those deposits, which had previously remained unquestioned. The above are the leading authorities among those who have questioned the lake theory as to the origin of these beds. On the other side the lacustrine origin of the rocks of the White River series, at least, has been maintained by Todd, Scott, Darton and others, though none of these authorities have thought it worth while to support their contentions by the production of any considerable direct or indirect evidence bearing on the case. Like the earlier writers they have, almost without exception, set forth their views as if they were well-established facts and beyond question or criticism. The following quotation from Scott is a fair example. In speaking of the Oligocene series, on page 507 of his *Introduction to Geology*, he says: "But in the interior regions are extensive fresh-water deposits which clearly should be referred to it and which form the White River stage. The largest body of water of this time occupied northeastern Colorado, southeastern Wyoming, much of western Nebraska and South Dakota." But the limits of this supposed Oligocene lake have lately been greatly extended by Darton, who has contended that it covered all of eastern and central Wyoming, and a considerable portion of Montana and North Dakota as well; so that one is at a loss to understand where lived the terrestrial mammals and reptiles whose remains are now found in such abundance in the deposits.

The lacustrine theory had its origin in the until recently universally accepted idea that all sedimentary rocks showing stratification

or bedding were deposited in either marine or fresh waters. Moreover the color-bands exhibited, more especially by the clays of the White River series, have been very generally mistaken for examples of stratification and lamination, while true lamination in the clays of this series is rare and usually of very limited extent both vertically and horizontally.

Dr. Matthew, in his *Memoir* already referred to, has set forth in very clear and concise language the principal stratigraphic and paleontologic evidences against the lacustrine theory as observed by him for these deposits in northeastern Colorado. It will be the chief purpose of the succeeding pages of this paper to extend these observations into southeastern Wyoming and western Nebraska and South Dakota, and to record some additional facts relating to the stratigraphy, paleontology and paleobotany of the beds, with especial reference to their bearing upon the origin and mode of deposition of the latter.

Matthew has already called attention to the physical and topographical difficulties, as well as to the lack of terraces and of certain stratigraphical characters which should exist if these deposits had their origin in a body of fresh water of a size comparable with that outlined by Scott. These difficulties, already serious, are only augmented by the increased dimensions of this lake proposed by Darton. If we confine it, however, to the much more restricted limits given by Dr. Scott we still have a lake of very considerable dimensions, greatly exceeding in size those of any fresh-water lake of modern times, with no barrier to the east or south to retain its waters, without recognizable terraces about its shores, and with a distribution of materials and of remains of fresh water, and of terrestrial plants and animals which are at least difficult, if not impossible, of explanation by the assumption of the presence of a great lake.

Character of the Materials in the White River Series.

We have already observed, while discussing the classification of the White River beds, the presence in them of frequent lenses of sandstones and conglomerates. These sandstone and conglomerate lenses are not arranged concentrically at varying altitudes about the margins of this supposed great lake, but extend as greatly elongated and narrow lenses far out into the very centre of the region which this lake has been supposed to have occupied. They occur at all

horizons, show frequent examples of cross-bedding and their irregular course, as well as the spheroidal shape of the pebbles they contain,[1] and the increased fineness of the materials of which they are composed as one proceeds from the margin toward the interior, are all characters strongly suggesting that they were deposited in river channels. Moreover, the materials of these sandstone and conglomerate lenses are not only coarser about the western borders of the beds, but the lenses are far more numerous in that region. Toward the interior these lenses converge and unite without spreading out laterally, so that in the region lying east of the Black Hills in South Dakota, at a distance of fifty to seventy-five miles from the mountains, the sandstones are finer, less frequent and are separated by greater areas of fine clays, just as the streams of the present day unite and become fewer in number as we proceed farther from their sources.

The Metamynodon and Protoceras sandstones, as well as certain intermediate and underlying sandstones, present many evidences, like those just enumerated, which strongly suggest that they were deposited in river channels. Taking the Protoceras sandstones as the most favorable example, owing to the greater extent to which they have been exposed by the subsequent erosion of the overlying sediments, they are seen to extend as a series of narrow elongated lenses from the summit of the Cheyenne and White River divide for several miles to the southward of the last-mentioned stream, where they pass beneath more recent deposits. Throughout their entire extent they exhibit frequent examples of cross-bedding, while the sands become finer and the channels fewer in number and broader and deeper as ones goes southward toward and across White River. That they have been removed by erosion over considerable areas lying between their present limits and the Black Hills is evident. At the summit of the Cheyenne and White River divide there are several of these sandstone lenses at approximately the same horizon. These bear many evidences of having been deposited in the channels of small streams or rivers pertaining to a single drainage system, which had its source somewhere in the

[1] A conglomerate accumulated by a running stream can usually be distinguished very readily from one formed on the beach of a lake or sea, by the shape of the contained pebbles. In the first instance the pebbles have been reduced to irregular spheroids by the rolling motion to which they have been submitted by the current. In the second they are more generally flattened disks.

present region of the Black Hills and was tributary to a much larger river coming from the southwest. These sandstone lenses appear to converge and unite as one proceeds toward White River, like the tributaries of recent streams. I am at a loss to understand how these greatly elongated sandstone lenses, confined laterally to at most only a few hundred yards in breadth, and necessitating the presence of strong currents, could have been deposited in the bottom of a great lake. For they appear not only to extend quite across the entire region which this lake has been supposed to have occupied, but these or very similar sandstones are found at intervals throughout the entire vertical and lateral extent of the beds, although as one recedes eastward from the western border they become less frequent and of finer grain. Such difficulties as those just mentioned, together with others to be referred to later, long ago demonstrated to the present writer the untenable nature of the lake theory as to the origin of these deposits.

If these beds had their origin in a great lake it may very naturally be asked, Where are the remains of the aquatic fauna which a lake of such dimensions may very reasonably be supposed to have contained? The reply has been made, and will be forthcoming from advocates of the lake theory, that the waters of this great lake were of such a saline or alkaline nature that it was incapable of supporting life. Hence the absence of the remains of aquatic animals. But I shall show presently that such bodies of water as did exist in this region during the deposition of these beds were not only not of such a nature, but that they were eminently fitted for the support of aquatic life and did in fact support such life, both plant and animal, in great abundance.

Again, if a lake deposit, how did the remains of terrestrial mammals and reptiles receive their present distribution throughout these beds? It has been maintained by advocates of the lake theory that the fine-grained, banded clays were deposited in the deep and quiet waters of the lake and the sandstone and conglomerate lenses along the shores and about the mouths of tributary streams, while the preservation and distribution of the remains of terrestrial mammals and reptiles was accomplished by the drifting about in the lake of dead carcasses brought down by the tributary streams. Such a theory requires conditions which are not only quite unreasonable but unparalleled elsewhere, both in the deposits of the lakes and seas of the present day and those of past geological epochs. Fur-

thermore it not only does not account for but is actually opposed to the present distribution of the fossils. If, as we are told, the fine clays were deposited over the deeper and quieter waters of the lake and the sandstones and conglomerates about the mouths of rivers and along the shores, why, I may ask, is it that the former contain absolutely by thousands the remains of giant land-tortoises, while these if not entirely absent are conspicuously rare in the sandstones, while the few examples of Trionyx, an aquatic turtle, have, in so far as I know, all been recovered from the sandstones? I have myself collected a number of these latter from the sandstones. If the land-tortoises were brought into the lake by the rivers, ought we not to expect that their remains would be found in at least as great an abundance in the sandstones as in the clays? Again, while it is quite possible to conceive of even a huge animal of such elephantine size as was Titanotherium as having met death by drowning or otherwise in or near some stream, where the dead body inflated by gases would be carried out by the current into the waters of the lake to sink later, allowing the bones to be preserved in the clays at the bottom, it is difficult to understand how such examples could be other than exceptional, and it is totally incapable of explaining the present distribution and abundance of such bones. In such a case as that just supposed it seems quite probable that once decomposition had proceeded far enough to weaken the body walls sufficiently to permit of the escape of the confined gases, the carcass would sink to the bottom and the bones of the skeleton be preserved in approximately their normal position relative to one another, just as are the skeletons of marine reptiles in the chalk beds of western Kansas or at Lyme-Regis in England. If this were the case we should expect to find complete skeletons at least fairly common, but they are in fact exceptionally rare, and for every even approximately complete skeleton to be found there are scores of isolated skulls and other bones. Taking Titanotherium as an example, I have myself collected nearly two hundred skulls of this animal, while the number of fairly complete skeletons at present known may be counted on the fingers of one hand. What is true of this animal applies likewise to the others found in the beds.

But, it will be asked, if the lake theory is so objectionable, why do you not offer a better? Such has already been done by Matthew, and it is the purpose of the present paper to support

in a somewhat modified form the theory advanced by him, extending his observations and adding certain additional facts observed by the present writer and bearing directly upon the subject.

Matthew's theory as to the origin of these deposits may best be described in his own language. Speaking of the conditions attending the deposition of these beds, he says: "The nature of the organic remains, where such have been found, seem to definitely negative the idea of any vast lake, and to favor less the theory of a series of lagoons and swamps than that of a broad, open and comparatively level plain, with shallow, probably wooded, rivers meandering over parts of it and deposits partly or chiefly brought by rivers, but in large part redistributed over the higher sodded grassland by the agency of the wind." With most of the principal features of this theory as applied by its author the present writer is in accord. I believe, however, that the materials on the whole partake more of the nature of fluviatile and flood-plain deposits than of those characteristic of prairie loess.

Paleontological Evidences.

The distribution, state of preservation, nature and character of the animal and plant remains found in the clays and sandstones, as well as the distribution of the latter, absolutely preclude the possibility of their having been deposited in a vast lake and favor the presence of streams meandering through low, broad, level, open or wooded valleys subjected in part at least to frequent inundations, conditions very similar to those at present prevailing in the interior of South America, about the headwaters of the Orinoco, the Amazon and the Paraguay and Parana Rivers.

Now it is evident that if such conditions prevailed in this region during the deposition of the White River beds there should remain certain evidences concerning it, such as filled-in river channels and small lagoons with their characteristic deposits and remains of the animal and vegetable life peculiar to each. Moreover some indication at least of the forests should remain and be found somewhere in this vast region. With these and many other points constantly in mind the writer passed a considerable portion of the seasons of 1900 and 1901 in exploring these deposits. Particular attention was given to ascertaining whether or not they contained an aquatic fauna and flora. The sandstone lenses were especially examined

with reference to this, for whether the deposits as a whole were of lacustrine origin or not, there could be little doubt as to the aqueous origin of the sandstones. Though for the most part remarkably barren of aquatic life, remains of Trionyx, fishes and crocodiles were found, and in one locality the casts of unios were observed in great numbers. A search in the clays of the Titanotherium and overlying Oreodon beds was rewarded with greater success, for numerous thin layers of limestone, varying in thickness from a fraction of an inch to a foot or more and always of limited areal extent, were discovered at many horizons rich in the remains of fresh-water plants and mollusca, such characteristically shallow-water forms as Chara, Limnæa, Physa and Planorbis occurring in the greatest abundance. I have submitted these mollusca to Drs. Dall, Pilsbry and Stanton, and all have assured me that they belong to species inhabiting swamps and small ponds, and could not have lived in the midst of a great lake; while Dr. Knowlton, who has examined the plants, finds in great abundance the stems and seeds of Chara, which, as all know, is distinctly an inhabitant of small springs, shallow ponds and brooks. The presence of these thin limestone layers with such characteristically swamp plants and mollusca as are Chara and Physa at various horizons throughout the White River series, and in the very midst of the region which was supposed to have been occupied by a great lake, and intercalated with the clays which advocates of the lake theory maintain were deposited in the deep and quiet waters, would appear to preclude the possibility of the existence of such a lake in White River times. Moreover remains of forests were found at several places and at different horizons throughout these beds. At various localities in the Hat Creek basin in Sioux County, Nebraska, I discovered remains of the silicified trunks of trees and seeds belonging especially to Hickoria and Celtis. These were found at various horizons from the middle Titanotherium beds to the very top of the Loup Fork. And in South Dakota, some twelve miles north of White River, opposite the mouth of Corn Creek, I discovered the remains of a no inconsiderable forest. Here in the upper Titanotherium beds and lower Oreodon beds there occur, actually by hundreds, the silicified stumps and partially decayed trunks of trees, weathering out of the fine clays of these deposits. It was noticeable that only the knots and lower stumps had been preserved. Nothing like complete trunks were to be observed, and the entire

aspect was that of the remains of a dead and decayed forest on the margin of some stream, where only the less destructible knots and stumps would endure sufficiently long to be finally covered up and preserved. In this same region there were discernible certain strata which seemed to indicate that during the deposition of these beds there had been at several horizons an accumulation of vegetable mould or humus, and on Dry Creek, some five miles northeast of Chadron, in Dawes County, Nebraska, I observed near the base of the Oreodon beds a stratum of some two feet of dark-colored humus, clearly indicating that this region had not been occupied by a great lake while this stratum was being deposited.

The advocates of the lake theory have always maintained that the fine clays of the Oreodon and Titanotherium beds were deposited in the deep and quiet waters of the lake, explaining the absence of the remains of an aquatic fauna, such as a lake of so great dimensions might in all reason be expected to maintain, on the theory that this lake was of such a saline or alkaline nature as to render its waters uninhabitable by crocodiles, turtles and fresh-water fishes. But I have shown that the remains of such animals do occur, though sparsely, wherever there is evidence of sufficient water to maintain them. The character and abundance of the mollusca and aquatic plants found in the thin limestone lenses throughout the clays show that such bodies of water as were present, although limited in area, were eminently well adapted to fresh-water life. The great abundance of land-tortoises in the clays and their almost complete absence in the sandstones is very strong if not positive evidence that the former were not deposited in the bottom of a great lake, for I do not believe that any one will assume to explain the present distribution of the remains of these land-turtles on the lake theory. After a careful consideration of the materials composing the White River deposits and the distribution and character of the fossils throughout the sandstones, conglomerates, clays and limestones, the present writer believes that the sandstones, conglomerates and a portion of the clays were deposited in river channels, while the limestone lenses, so rich in the remains of aquatic plants and mollusks, originated in shallow ponds and lakes scattered over the higher table-lands and the broad flood-plains of the rivers, where for the most part the finer clays were deposited by occasional inundations and through the agency of the winds. Such a theory as to the origin of the White River

beds appears to the writer not only to be in harmony with all the observed facts, but moreover the conditions which it presupposes are paralleled by existing conditions in other parts of the earth's surface.

The following description of the conditions at present prevailing about the sources of the Parana and Paraguay Rivers in central South America has been furnished me by Mr. H. H. Smith, who has spent several years in that region and has had exceptional advantages for studying the physical conditions that obtain about the headwaters of these streams and their tributaries. He says:

"Ascending the River Paraguay from Asuncion, the river hugs the higher lands of the eastern or Paraguay side or is separated from them by strips of alluvium. On the western or Chaco side the ground is always low and flat, hardly above reach of the annual freshets and proportionally a little lower toward the north. During the rains water covers large spaces of these flatlands, but it does not come from the river and is gradually drained away after the rains cease. Above the mouths of the Vermejo the Chaco bank is at first covered with low forest; farther north great areas have a scattered growth of Carandá palms with grass beneath, but with no other vegetation. The Chaco plains extend far inland to the table-land of Bolivia, which is said to fall abruptly to the plain.

"At latitude 21° 26′ 40″ S. the river flows through a narrow pass, the *Fecho dos Morros*, between two rocky hills. The hill on the eastern side is connected by high ground with the Brazilian table-land. That on the western side appears from the river to form one of a number of isolated hills which rise from the Chaco plain. It may be, however, that there is rocky ground extending westward to the Bolivian table-land, and perhaps connected with the Corumbá hills. This region, however, is practically unexplored, and nothing definite can be said about it. If there is a connection with the Bolivian highland, the basin of the upper Paraguay is completely enclosed like a lake, with only the narrow outlet at the Fecho dos Morros. If the hill on the western side is isolated, it is probably one of a chain which extends inland and imperfectly closes the Paraguay basin on this side.

"Above the Fecho dos Morros the character of the vegetation changes; the Carandá palms disappear; there is left only open grassland, with lines of bushes here and there and often a thin

fringe of forest on the river bank. The river at the flood season covers these lands almost entirely. It must be remembered that the upper Paraguay rises about thirty feet annually.

"All the flatlands above the Fecho dos Morros to Villa Maria—over four hundred miles in a direct line—are subject to river floods, and these are deepest toward the north. The width of the flood-plain at the mouth of the São Lourenço can hardly be less than one hundred and fifty miles from the rocky lands on the east to the base of the Serra dos Dourados. The whole region is a labyrinth of lakes, ponds, swamps, channels and islands in a grassy plain, the only forest being near the river. I had a fine view of this plain from the foothills of the Dourados; even the flood-plains of the Amazon cannot compare with it in its tangle of land, water and marshes. Only the most experienced canoeman can thread his way through it; generally travelers trust to the Guató Indians, who are the only inhabitants of the region and literally live in canoes. Castelnau was lost there and only found the river channel with great difficulty. We were lost or partly lost for a few hours, though we had three experienced hands.

"This is the region called Lake Xaraés, or Charaés, by the old explorers; Brazilians called it the Pantanaes, literally The Marshes. Even at low water at least one-fourth of it is flooded: when the river is at its highest the whole plain is a vast lake covered with floating grass and weeds; it is possible to pass almost straight across it in a canoe, though with great difficulty. Only a few islands remain here and there; jaguars, deer and other animals take refuge on them, and they are favorite hunting grounds of the Guatós.

"The rainy season is from October to April, the heaviest rains being toward the last; the small rivers from the highlands are flooded in March and April, and pour their waters over the flood-plain. But it takes a long time for these waters to spread over the plain. Consequently the highest waters on the plain are in July and August. Then they gradually drain away through the Fecho dos Morros, and the lowest waters are found about February.

"The eastern and northern sides of the flood-plains are bordered by low rocky lands which extend for a few miles inland: then they rise precipitously 1500 or 1800 feet to the Brazilian plateau. The

line of precipices forming the plateau may be traced from Villa Maria to near Miranda.

"On the Dourados side the case is different. Long bays of the flood-plain run back among the hills and often contain lakes of considerable size. The Dourados chain itself is narrow and on the other side are more floodlands, the region called "*Ceo e Terra*" by the Brazilians. The Brazilian-Bolivian Boundary Commission tried to pass over this land but had to turn back.

"The Paraguayan flood-plains are connected with the *Ceo e Terra* region by several strips which cut the Dourados chain. Hence the Dourados are like a chain of islands.

"A narrow neck of rocky but low land divides the Paraguayan flood-plain from similar plains in the Guaporé; those on the Guaporé are continuous to the junction of the Madeira where there are rapids; beyond that a flood-plain extends to the Amazon, broadening out. The Amazonian plain is connected in much the same way with the Orinoco. The Orinoco, Amazon and Paraguay are like each other in their flood-plains, which broaden out as we ascend the rivers.

"Except for a single break at the Fecho dos Morros (which may not be a continuous wall) a great plain stretches from Villa Maria to Rosario and beyond. The Xaraés, Chaco and Pampa differ only in their relations to the river floods. The pampas are above reach of the floods; the Chaco plains are also above the floods, but so low that the water drains off slowly; the Xaraés are covered at high water. The Paraguay and its continuation, the Paraná, cut deeper and deeper into the plains as they flow southward, hence the differences in physical features, which are more apparent than real."

From the above description it will be seen that the flood-plain of the Paraguay at the mouth of the São Lourenço has a width of one hundred and fifty miles and that it broadens as we ascend the river. It is a well-known fact, as stated by Mr. Smith, that the flood-plains of the upper Paraguay, Amazon and Orinoco Rivers are confluent, and that a vast region about the headwaters of those streams possesses physical conditions in every way similar to those just described as obtaining over the flood-plains of the upper Paraguay. Here it appears to the present writer we have a region of equal or greater area than that occupied by the Oligocene and Miocene deposits of our Western plains, with all the physical

conditions necessary for the deposition and present distribution of the sandstones, clays and conglomerates, together with the preservation of remains of the faunas characteristic of each.

Many have noticed and Prof. J. E. Todd has recorded the presence of great deposits of bones at various localities in the White River beds. He describes them as literally covering the ground in places where they have weathered out over areas frequently of more than an acre in extent. It is not only difficult, but I think impossible to account for these accumulations of bones of terrestrial animals at the bottom and in the very middle of a great lake. Since the surrounding clays are usually almost destitute of bones, it is difficult to understand how the dead carcasses of so many animals were driven or drawn as by a magnet to so limited an area. Accepting the other theory, however, we have seen how during the rainy season the deer, tapirs and other animals are driven to the islands over the flood-plains of the great South American rivers. Since in exceptionally high freshets the lower of these islands become submerged it is not difficult to understand how great numbers of these animals must annually perish, and indeed it is a well-known fact that frequently great numbers of them are caught on low islands and, driven by the rising waters to more limited confines, they are finally all drowned when the island becomes entirely submerged. To such or similar conditions the great deposits of bones in the Oligocene and Miocene deposits of the West may owe their origin. I have frequently observed these deposits, though not covering so great an area as that recorded by Todd, and I have always without exception noted that in the Oligocene beds they occurred in the very fine clays, while in the upper or Miocene deposits they occur in the finer sandstones. Although bones are fairly abundant in the sandstones of all these series of beds, I never observed these extremely rich deposits in the coarse sandstones or conglomerates.

The above facts, together with those brought forward by Dr. Matthew, have driven me, contrary to my earlier opinion, to reject the theory of a great lake and accept that of small lakes, flood-plains, river channels and higher grass-covered pampas as the conditions prevailing over this region in Oligocene and Miocene times.

Carnegie Museum, *March 31, 1902.*